Discovery of Oxygen in the Sun by Photography, and a new Theory of the Solar Spectrum.

By Professor Henry Draper, M. D.

(*Read before the American Philosophical Society, July* 20, 1877).

I propose in this preliminary paper to indicate the means by which I have discovered Oxygen and probably Nitrogen in the Sun, and also to present a new view of the constitution of the Solar Spectrum.

Oxygen discloses itself by bright lines or bands in the Solar Spectrum and does not give dark absorption lines like the metals. We must therefore change our theory of the Solar Spectrum and no longer regard it merely as a continuous spectrum with certain rays absorbed by a layer of ignited metallic vapors, but as having also bright lines and bands superposed on the background of continuous spectrum. Such a conception not only opens the way to the discovery of others of the non-metals, sulphur, phosphorus, selenium, chlorine, bromine, iodine, fluorine, carbon, &c., but also may account for some of the so-called dark lines, by regarding them as intervals between bright lines.

It must be distinctly understood that in speaking of the Solar Spectrum here, I do not mean the spectrum of any limited area upon the disc or margin of the Sun, but the spectrum of light from the whole disc. I have not used an image of the Sun upon the slit of the spectroscope, but have employed the beam reflected from the flat mirror of the heliostat without any condenser.

In support of the above assertions the accompanying photograph of the Solar spectrum with a comparison spectrum of Air, and also with some of the lines of Iron and Aluminium is introduced. The photograph itself is absolutely free from handwork or retouching. It is difficult to bring out in a single photograph the best points of these various substances, and I have therefore selected from the collection of original negatives that one which shows the Oxygen coincidences most plainly. There are so many variables among the conditions which conspire for the production of a spectrum that many photographs must be taken to exhaust the best combinations. The pressure of the gas, the strength of the original current, the number of Leyden jars, the separation and nature of the terminals, the number of sparks per minute, and the duration of the interruption in each spark, are examples of these variables.

In the photograph the upper spectrum is that of the Sun, and above it are the wave-lengths of some of the lines to serve as reference numbers. The wave-lengths used in this paper have been taken partly from Angström and partly from my photograph of the diffraction spectrum published in 1872. The lower spectrum is that of the open air Leyden spark, the terminals being one of Iron and the other of Aluminium. I have photographed Oxygen, Nitrogen, Hydrogen and Carbonic Acid as well as other gases in Plücker's tubes and also in an apparatus in which the pressure could be varied, but for the present illustration, the open air spark was, all things considered, best. By other arrangements the Nitrogen lines can readily be made as sharp as the Oxygen are here, and the Iron lines may be increased in number and distinctness. For the metals the electric arc gives the best photographic results, as Lockyer has so well shown, but as my object was only to prove by the Iron lines that the spectra had not shifted laterally past one another, those that are here shown at 4325. 4307. 4271. 4063. 4045. suffice. In the original collodion negative many more can be seen. Below the lower spectrum are the symbols for Oxygen, Nitrogen, Iron and Aluminium.

No close observation is needed to demonstrate to even the most casual observer that the Oxygen lines are found in the Sun as bright lines, while the Iron lines have dark representatives. The bright Iron line at G (4307), on account of the intentional overlapping of the two spectra, can be seen passing up into the dark absorption line in the Sun. At the same time the quadruple Oxygen line between 4345 and 4350 coincides exactly with the bright group in the Solar Spectrum above. This Oxygen group alone is almost sufficient to prove the presence of Oxygen in the Sun, for not only does each of the four components have a representative in the Solar spectrum, but the relative strength and the general aspect of the lines in each case is similar. I do not think that in comparisons of the spectra of the elements and Sun, enough stress has been laid on the general appearance of lines apart from their mere position; in photographic representations this point is very prominent. The fine double line at 4319. 4317. is plainly represented in the Sun. Again there is a remarkable coincidence in the double line at 4190. 4184. The line at 4133 is very distinctly marked. The strongest Oxygen line is the triple one at 4076. 4072. 4069., and here again a fine coincidence is seen though the air spectrum seems proportionately stronger than the solar. But it must be remembered that the Solar spectrum has suffered from the transmission through our atmosphere, and this effect is plainest in the absorption at the ultra-violet and violet regions of the spectrum. From some experiments I made in the Summer of 1873, it appeared that this local absorption is so great, when a maximum thickness of air intervenes, that the exposure necessary to obtain the ultra-violet spectrum at sunset was two hundred times as long as at mid-day. I was at that time seeking for atmospheric lines above H like those at the red end of the spectrum, but it turned out that the absorptive action at the more refrangible end is a progressive enfeebling as if a wedge of neutral tinted glass were being drawn lengthwise along the spectrum towards the less refrangible end.

I shall not attempt at this time to give a complete list of the Oxygen lines with their wave lengths accurately determined, and it will be noticed that some lines in the air spectrum which have bright analogues in the sun are not marked with the symbol of Oxygen. This is because there has not yet been an opportunity to make the necessary detailed comparisons. In order to be certain that a line belongs to Oxygen, I have compared, under various pressures, the spectra of Air, Oxygen, Nitrogen, Carbonic Acid, Carburetted Hydrogen, Hydrogen and Cyanogen. Where these gases were in Plücker's tubes a double series of photographs has been needed, one set taken with, and the other without Leyden jars.

As to the spectrum of Nitrogen and the existence of this element in the sun there is not yet certainty. Nevertheless, even by comparing the diffused Nitrogen lines of this particular photograph, in which Nitrogen has been sacrificed to get the best effect for Oxygen, the character of the evidence appears. The triple band between 4240. 4227. if traced upward into the Sun has approximate representatives. Again at 4041. the same thing is seen, the solar bright line being especially marked. In another photograph the heavy line at 3995. which in this picture is opposite an insufficiently exposed part of the Solar Spectrum shows a comparison band in the Sun.

The reason I did not use air in an exhausted Plücker's tube for the production of a photograph to illustrate this paper, and thus get both Oxygen and Nitrogen lines well defined at the same time, was partly because a brighter light can be obtained with the open air spark on account of the stronger current that can be used. This permits the slit to be more closed and of course gives a sharper picture. Besides the open air spark enabled me to employ an iron terminal, and thus avoid any error arising from accidental displacement of the reference spectrum. In Plücker's tubes with a Leyden spark the Nitrogen lines are as plain as those of Oxygen here. As far as I have seen Oxygen does not exhibit the change in the character of its lines that is so remarkable in Hydrogen under the influence of pressure as shown by Frankland and Lockyer.

The bright lines of Oxygen in the spectrum of the solar disc have not been hitherto perceived probably from the fact that in eye observation bright lines on a less bright background do not make the impression on the mind that dark lines do. When attention is called to their presence they are readily enough seen, even without the aid of a reference spectrum. The photograph, however, brings them into a greater prominence. From purely theoretical considerations derived from terrestrial chemistry, and the nebular hypothesis, the presence of Oxygen in the sun might have been strongly suspected, for this element is currently stated to form eight-ninths of the water of the globe, one-third of the crust of the earth, and one-fifth of the air, and should therefore probably be a large constituent of every member of the solar system. On the other hand the discovery of Oxygen and probably other non-metals in the Sun gives increased strength to the nebular hypothesis, because to many persons the absence of this important group has presented a considerable difficulty.

At first sight it seems rather difficult to believe that an ignited gas in the solar envelope should not be indicated by dark lines in the solar spectrum, and should appear not to act under the law "a gas when ignited absorbs rays of the same refrangibility as those it emits." But in fact the substances hitherto investigated in the sun are really metallic vapors, Hydrogen probably coming under that rule. The non-metals obviously may behave differently. It is easy to speculate on the causes of such behavior, and it may be suggested that the reason of the non-appearance of a dark line may be that the intensity of the light from a great thickness of ignited Oxygen overpowers the effect of the photosphere just as if a person were to look at a candle flame through a yard thickness of ignited sodium vapor he would only see bright sodium lines, and no dark absorption lines. Of course, such an explanation would necessitate the hypothesis that ignited gases such as Oxygen give forth a relatively large proportion of the solar light. In the outburst of *T Coronæ* Huggins showed that Hydrogen could give bright lines on a background of spectrum analogous to that of the Sun.

However all that may be, I have no doubt of the existence of substances other than Oxygen in the Sun which are only indicated by bright lines. Attention may be called to the bright bands near G, from wave lengths 4307 to 4337, which are only partly accounted for by Oxygen. Farther investigation in the direction I have thus far pursued will lead to the discovery of other elements in the Sun, but it is not proper to conceal the principle on which such researches are to be conducted for the sake of personal advantage. It is also probable that this research may furnish the key to the enigma of the D_3 or Helium line, and the 1474 K or Corona line. The case of the D_3 line strengthens the argument in favor of the apparent exemption of certain substances from the common law of the relation of emission and absorption, for while there can be no doubt of the existence of an ignited gas in the chromosphere giving this line, there is no corresponding dark line in the spectrum of the solar disc.

In thus extending the number of elements found in the Sun we also increase the field of inquiry as to the phenomena of dissociation and recomposition. Oxygen especially from its relation to the metals may readily form compounds in the upper regions of the solar atmosphere which can give banded or channeled spectra. This subject requires careful investigation. The diffused and reflected light of the outer corona could be caused by such bodies cooled below the self luminous point.

This research has proved to be more tedious and difficult than would be supposed because so many conditions must conspire to produce a good photograph. There must be a uniform prime moving engine of two horse power, a dynamo-electric machine thoroughly adjusted, a large Ruhmkorff coil with its Foucault break in the best order, a battery of Leyden jars carefully proportioned to the Plücker's tube in use, a heliostat which of course involves clear sunshine, an optical train of slit, prisms, lenses and camera well focussed, and in addition to all this a photographic laboratory in such complete condition that wet sensitive plates can be prepared which will bear an exposure of fifteen minutes and a prolonged development. It has been difficult to keep the Plücker's tubes in order; often before the first exposure of a tube was over the tube was ruined by the strong Leyden sparks. Moreover, to procure tubes of known contents is troublesome. For example, my hydrogen tubes gave a spectrum photograph of fifteen lines of which only three belonged to hydrogen. In order to be sure that none of these were new hydrogen lines it was necessary to try tubes of various makers, to prepare pure hydrogen and employ that, to examine the spectrum of water, and finally to resort to comparison with the Sun.

The object in view in 1873, at the commencement of this research was to secure the means of interpreting the photographs of the spectra of stars and other heavenly bodies obtained with my 28 inch reflector. It soon appeared that the spectra of Nitrogen and other gases in Plücker's tubes could be photographed and at first some pictures of Hydrogen, Carbonic Acid and Nitrogen were made because these gases seemed to be of greatest astronomical importance on account of their relation to stars, nebulæ and comets. Before the subject of comparison spectra of the Sun was carefully examined there was some confusion in the results, but by using Hydrogen the source of these errors was found out.

But in attempting to make a prolonged research in this direction, it soon appeared that it was essential to be able to control the electrical current with precision both as to quantity and intensity, and moreover, to have currents which when once adjusted would remain constant for hours together. These conditions are almost impossible to attain with any form of battery, but on the contrary are readily satisfied by dynamo electric machines. Accordingly, I sought for a suitable dynamo-electric machine and motor to drive it, and after many delays procured a combination which is entirely satisfactory. I must here acknowledge my obligations for the successful issue of this search to Professor George F. Barker, who was the first person in America to procure a Gramme machine. He was also the first to use a Brayton engine to drive a Gramme.

The dynamo-electric machine selected is one of Gramme's patent, made in Paris, and is a double light machine, that is it has two sets of brushes, and is wound with wire of such a size as to give a current of sufficient intensity for my purposes. It is nominally a 350 candle light machine, but the current varies in proportion to the rate of rotation, and I have also modified it by changing the interior connections. The machine can produce as a maximum a light equal to 500 standard candles, or by slowing the rotation of the bobbin the current may be made as feeble as that of the weakest battery. In practical use it is sometimes doing the work of more than 50 large Grove nitric acid cells, and sometimes the work of a single Smee.

The Gramme machine could not be used to work an induction coil when it first reached me, because when the whole current was sent through the Foucault interruptor of the Ruhmkorff coil, making 1000 breaks per minute, the electro-magnets of the Gramme did not become sufficiently magnetized to give an appreciable current. But by dividing the current so that one pair of the metallic brushes, which collect from the revolving bobbin, supplied the electro-magnets, the other pair could be used for exterior work, no matter whether interrupted or constant. The current obtained in this way from one pair of brushes when the Gramme bobbin is making 1200 revolutions per minute is equal to 100 candles, and is greater in quantity and intensity than one would like to send through a valuable induction coil. I usually run the bobbin at 622 revolutions per minute, and this rate will readily give 1000 ten-inch sparks per minute with the 18 inch coil. Of course a Plücker's tube lights up very vividly and generally, in order to get the maximum effect I arrange the current so that the aluminium terminals are on the point of melting. The glass, particularly in the capillary part often gets so hot as to char paper. The general appearance of the machine is shown in Fig. 1.

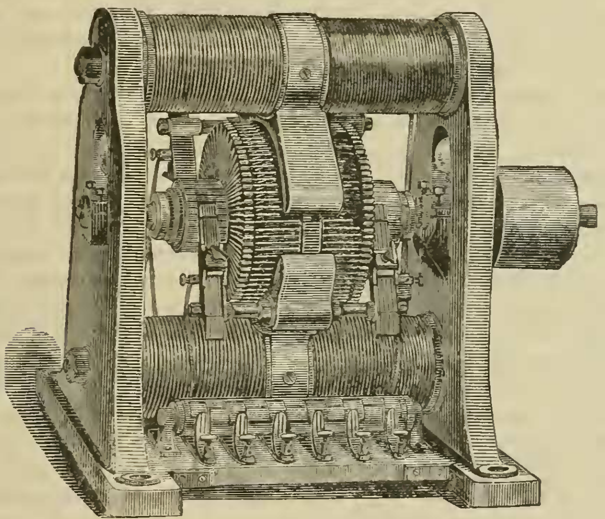

Fig. 1.—The Gramme Machine.

As long as the Gramme bobbin is driven at a steady rate the current seems to be perfectly constant, but variations of speed make marked differences in the current and this is especially to be avoided when one is so near the limit of endurance of Plücker's tubes. A reliable and constant motor is therefore of prime importance for these purposes. A difference of one per cent. in the speed of the engine sometimes cannot be tolerated, and yet at another time, one must have the power of increasing and diminishing the rate through wide limits. The only motor, among many I have examined and tried, that is perfectly satisfactory, is Brayton's Petroleum Ready Motor.

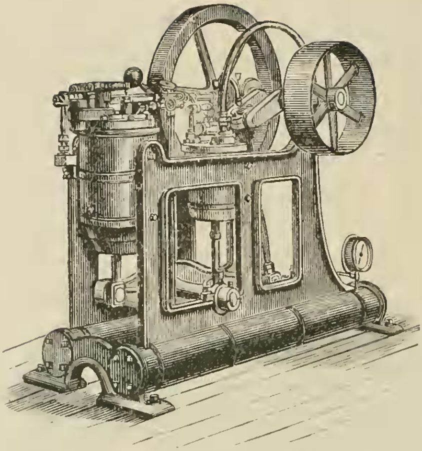

Fig. 2.—Brayton's Petroleum Motor.

This remarkable and admirable engine acts like an instrument of precision. It can be started with a match and comes to its regular speed in less than a minute; it preserves its rate entirely unchanged for hours together. Moreover, it is economical, cleanly, and not more noisy than a steam engine. The one of two horse power I have, ran for six months, day and night, supplying water and air to the aquaria in the Centennial Exhibition at Philadelphia. At any time on going into the laboratory it can be started in a few seconds even though it has not been running for days.

Henry Draper's Observatory,
Hastings-on-Hudson, New York.

Note on the Exactitude of the French Normal Fork; a Reply to the paper of Mr. A. J. Ellis; by Rudolph König, Ph. D.

(*Communicated by Professor Barker to the American Philosophical Society. July* 20, 1877.)

An attack, as strange as it was unexpected, has just been made in England upon the exactitude of the official French fork. Mr. Alexander J. Ellis, having found that the notes of a tonometer, composed of sixty-five harmonium reeds, constructed by Mr. Appunn, do not agree with this fork, has considered himself entitled to assert, in a paper published in the Journal of the Society of Arts (May 25, 1877), and in Nature (May 31, 1877) that the normal French fork La_3 gives, not 870 single vibrations, as has been hitherto supposed, but 878 single vibrations. Mr. Ellis, having established the further fact that the forks constructed by me are in perfect